CYLINDER CRANKCASE, PROCEDURE FOR MANUFACTURING THE CYLINDER BUSHINGS FOR THE CYLINDER CRANKCASE, AND PROCEDURE FOR MANUFACTURING THE CYLINDER CRANKCASE WITH THESE CYLINDER BUSHINGS

The invention relates to a light metal cylinder crankcase for combustion engines according to the generic term of claim 1. It also relates to a procedure for manufacturing cylinder bushings for a cylinder crankcase and to a procedure for manufacturing a cylinder crankcase with such cylinder bushings.

For purposes of lightweight construction, grey cast iron is currently being substituted by aluminum alloys in cylinder crankcases of combustion engines for motor vehicles. While grey cast iron is also suitable for the cylinder bearing surface, aluminum cast alloys are reinforced in this area by cylinder bushings.

Known from DE 196 05 946 C1 is a cylinder bushing made out of a molybdenum running layer and an outside aluminum alloy layer, whose outside is profiled. Both layers are formed via thermal spraying on a rotating mandrel. Using molybdenum, an anti-adhesive, a mandrel with a hard chromium layer, etc. reduces the adhesion of the running layer to the mandrel to a point where the bushings can be taken off the mandrel.

When casting the cylinder crankcase, the cylinder bushings arranged on barrels in the mold with their profiled outside surface are positively joined with the casting material. The heavy molybdenum running layer

gives the known cylinder bushing considerable weight. In addition, there is a danger that the bushings will loosen, the cylinder will shift, and hence the blow-by values will increase. Residues from the combustion process can also get into the micro-gap at the phase boundary between the casting material and the bushings.

To improve the bonding of the cylinder bushing to the casting material of the cylinder crankcase, DE 196 34 504 A1 describes abrasive blasting of the surface of the cylinder bushing with sharp-edged particles to achieve a roughness of 30 - 60 µm in the form of pyramidal protuberances.

Since the oxide skin on an aluminium body to be poured into an aluminium casting material prevents bonding to the casting material, DE 197 45 725 A1 describes mechanically destroying the oxide skin on the pouring body through thermal spraying, wherein the resultant oxide particles are distributed in the spraying layer. In addition, the spraying material particles that did not completely melt on impact project out of the spraying layer, which improves the connection with the casting material. A nickel or molybdenum alloy is used as the spraying material.

The object of the invention is to provide a lightweight, easily manufactured cylinder bushing, which leads to a flawless, rigid bonding to the casting material of the cylinder crankcase for the life cycle of the combustion engine.

This is achieved according to the invention with the cylinder crankcase described in claim 1. Claims 2 to 8 describe advantageous embodiments of the cylinder

crankcase according to the invention. Claim 9 describes a preferred procedure for manufacturing the cylinder bushings, which is configured in an advantageous manner by claims 10 to 22. Claim 23 relates to a preferred procedure for manufacturing a cylinder crankcase, which is developed further in an advantageous manner by claims 24 and 25.

In the cylinder crankcase according to the invention, the outside bonding layer of the cylinder bushing is formed by thermal spraying, performed in such a way as to form an spraying layer with a high open porosity of at least 10 %v/v, in particular 30 - 70 %v/v.

The layer thickness of the bonding layer preferably measures 60 µm - 800 µm. To bind a high open porosity, the bonding layer is preferably generated with a coarse-grained spraying powder with a grain size of 60 µm - 400 µm, in particular 90 µm - 250 µm. Therefore, the average grain size of the spraying powder in the bonding layer preferably measures more than 100 µm, in particular more than 130 µm. When using such a coarse-grained spraying powder to spray a very thin bonding layer, only one layer with the correspondingly high roughness can be formed instead of an open porous layer.

While casting light metal cylinder crankcase, the open, porous or rough layer formed in this way results in a material tight connection between the cylinder bushing and the cylinder crankcase.

In a molten state, light metals, i.e., in particular aluminum and magnesium and alloys thereof, form an outside oxide skin produced by the reaction of the light

metal and the ambient oxygen. The oxide skin protects the melt flowing inside against further oxidation.

When pouring in the cylinder bushings, contact between the oxide skin and cylinder bushing surface initially takes place as the molten metal flows in. Due to its chemical stability and low tendency toward wetting relative to solid bodies, e.g., the cylinder bushings, the oxide skin does not contribute to the connection between the solid body and surrounding casting material. Therefore, only a very limited material tight connection can be achieved in previous bushing systems.

The high roughness or open porosity of the bonding layer of the cylinder bushing according to the invention causes the oxide skin of circulating light molten metal to tear open from time to time, so that there is direct contact between the melted mass and the surface of the bonding layer. The oxide skin of the melted mass is uninterruptedly penetrated by the fine tips of the porous, rough surface of the bonding layer generated through thermal spraying.

After the oxide skin tears, the smelt infiltrates the porous bonding layer. This leads to direct contact between the melted mass and the bonding layer surface, producing a material tight connection. In addition, the high level of heat supplied from the surrounding casting material to the bonding layer causes the bonding layer to melt open on the surface. This produces a high degree of material tight bond between the bonding layer of the cylinder bushing and the cylinder crankcase. In other words, according to the invention, at least 60 %, preferably at least 80 %, and in particular at least 90 % of the bonding layer of the cylinder bushing relative to

the cylindrical jacket surface of the bonding layer is connected with the casting material of the cylinder crankcase in a material tight manner. The bonding level can here be determined by ultrasound.

The material tight bond of the cylinder bushings to the surrounding casting material ensures a flawless anchoring of the cylinder bushings in the cylinder crankcase for the lifetime of the combustion engine. The material tight bond results in a smooth flow of heat through the phase boundaries. This also prevents thermally induced warping.

The thermally sprayed, tribologically optimised cylinder bushings according to the invention can be poured into commercially available, inexpensive aluminum alloys.

The advantage to thermal spraying is that a nearly freely selectable material composition reflecting local requirements is possible, in comparison to other techniques. In this case, the cylinder bushing manufactured according to the invention via thermal spraying can be adapted in terms of alloy composition relative to both, its tribological properties on the bearing surface, and to the bonding properties on the motor block side. The material comprising the cylinder bearing surface must also be corrosion resistant. In addition, it must lend itself to machining, so that the cylinder bushing can be sized to operating dimensions after poured.

A carrier layer is preferably first thermally sprayed onto a mandrel as the molded part according to the invention to manufacture the cylinder bushing. After the carrier layer has been sprayed on, the running layer is applied though thermally spraying, and then the bonding

layer is applied on the running layer through thermal spraying.

The cylinder bushing blank fabricated in this way is then removed from the mandrel, wherein the slight adhesion of the carrier layer to the mandrel makes it easier to detach the blank from the mandrel.

The blanks are situated in the casting mold on barrels for manufacturing the cylinder crankcase. After casting and removing the cylinder crankcase from the mold, the carrier layer is removed and the running layer is sized to operating dimensions via machining.

All known procedural variations can be used for thermal spraying; this applies both, the spraying materials (powder or wire) and the type of energy source (flame, electric arc, plasma).

To ensure that the cylinder bushing according to the invention has a sufficient dimensional stability, it preferably has a wall thickness of 1 mm to 5 mm. Therefore, the bushing can be stored and handled without any problems from manufacture to pouring. Cylinder bushings can be manufactured according to the invention with standard diameters and lengths for all common engine types.

The mandrel preferably consists of tool steel or another material that is not melted open during thermal spraying. The mandrel is made to rotate during the thermal spraying of the individual layers of the cylinder bushing according to the invention.

The mandrel has the same dimensions as the barrels so that the bushings can be form-fit on the barrels while pouring. Accordingly, the mandrel can be conically designed with the same cone angle, e.g., 0.5° as the sleeves, so that the cylinder bushing blanks can be slipped onto the sleeves in a form-fitting manner.

To simplify the removal of the cylinder bushing blank from the mandrel, the mandrel can be hollow, so that it can be cooled with a medium, e.g., water. After thermal spraying, the mandrel can then be shrunk out of the still hot thermal cylinder bushing blank via cooling. The mandrel can also be removed by pressing it out of the cylinder bushing blank.

According to the invention, all known spraying procedures can be used as the thermal spraying procedure. Only one spraying procedure need be used for manufacturing the entire cylinder bushing. For economic reasons and in view of the respective layer properties, however, a combination of different procedures is preferably used.

The carrier layer is preferably manufactured via flame spraying with spraying wire, since this procedure is particularly cost effective. Preferably tin, zinc, aluminum and alloys thereof are used as the spraying materials for the carrier layer, since they yield a sufficient adhesion of the carrier layer to the mandrel, and also ensure that the completely sprayed bushing can be easily detached from the mandrel. The carrier layer preferably has a thickness of 20 µm to 500 µm, in particular 50 µm to 100 µm. The carrier layer is generally required in the cylinder bushing according to the invention in particular when the running layer consists of a light metal alloy that would adhere to the

mandrel in such a way without a carrier layer that the cylinder bushing could not be detached from the mandrel without any destruction.

For reasons of weight, the running layer according to the invention consists of a light metal alloy, in particular an aluminum or magnesium alloy, namely a tribologically suitable, corrosion-resistant light metal alloy, and is preferably an aluminum-silicon alloy with an Si content in particular of 12 to 50 %w/w. The tribological properties may leave something to be desired at an Si content of < 12 %w/w, while the material is most often brittle, and hence difficult to process, at an Si content of > 50 %w/w.

The light metal alloy can contain other tribologically active additives, e.g., silicon carbide, graphite or molybdenum.

If an Al-Si alloy is used for the running layer, it can additionally contain the following alloy constituents by weight:

Fe: 0.5 - 2.0 %, preferably 0.5 - 1.5 %
Ni: 0.5 - 2.0 %, preferably 0.5 - 1.5 %
Mg: 0.5 - 2.0 %, preferably 0.5 - 1.5 %
Cu: 0.5 - 2.0 %, preferably 0.5 - 1.5 %

These alloy constituents increase the hardness and heat resistance of the running layer.

The running layer can be manufactured via atmospheric plasma spraying (APS), flame spraying and high-velocity flame spraying (HVOF) with a spraying powder. Use can also be made of a special procedure in the area of high-

velocity flame spraying, which has become known under the name CGDM (cold-gas dynamic spray method).

When using a spraying powder, the average grain size preferably lies under 100 µm, in particular under 80 µm, wherein a sieve fraction of between 10 µm and 125 µm is preferably used to achieve a tribologically suitable corrosion-proof and machinable running surface. However, the running surface can also be manufactured with wire spraying materials, e.g., via wire flame spraying or arc spraying. Given the wide range of materials, however, powder spraying is generally preferred.

In the completely processed state, the running layer in the cylinder crankcase preferably has a thickness of 0.5 mm to 3 mm, in particular 1 mm to 2 mm.

The porous bonding layer of the cylinder bushing according to the invention can be formed through the use of a spraying powder with a corresponding high grain size and a suitable thermal spraying procedure. To this end, the spraying powder preferably has an average grain size of between 60 µm and 400 µm, in particular exceeding 100 µm, in particular exceeding 150 µm. A sieve fraction of between 90 µm and 250 µm is preferably used. All powder procedures can be used as the thermal spraying procedure, in particular flame or plasma spraying. A spraying distance of 50 mm to 400 mm, in particular 100 mm to 250 mm, can be used for flame spraying.

However, a spraying wire can also be used, wherein the porosity of the bonding layer is then achieved by setting the appropriate process parameters, e.g., a greater spraying distance.

To ensure a material tight bond to the casting material comprised of light metal, the spraying material for the bonding layer consists of a similar type of light metal alloy. This means that, since the casting material is normally an aluminum alloy, the bonding layer also consists of an aluminum alloy. However, the casting material and bonding layer can also consist of a magnesium alloy, for example.

The material used for spraying the bonding layer is preferably adapted to the running layer material on the one hand, and the casting material on the other. In other words, if the casting alloy consists of an Al-Si alloy and the running layer consists of an Al-Si alloy, an Al-Si alloy is preferably also used for the bonding layer. The Si content of the Al-Si alloy of the bonding layer here preferably ranges between the Si content of the Al-Si casting alloy and that of the running layer alloy. In other words, if a casting alloy comprised of Al-Si with an Si content of 9 to 10 %w/w and a running layer comprised of Al-Si with an Si content of 25 %w/w are used, the Si content of the Al-Si alloy of the bonding layer can range between 10 and 25 %w/w, for example. It is also possible to implement a gradated transition for the bonding layer composition between the running layer and the casting alloy by correspondingly changing the spraying material while spraying the bonding layer. The process parameters can also be changed to alter the porosity of the bonding layer from the running layer to the casting material.

Using similar procedures and materials for the running layer and bonding layer results in an intimate bond between the running layer and bonding layer. At the same

time, the open porous structure of the bonding layer leads to a material tight bond of the casting alloy, not only to the surface of the bonding layer, but deep into the layer.

The bonding layer thickness can range between 60 µm and 800 µm, and preferably lies between 100 µm and 500 µm.

The thermally sprayed cylinder bushing blank manufactured in this way can be poured into the cylinder crankcase immediately after the spraying process.

However, the cylinder bushing blank is preferably subjected to heat treatment before poured, to achieve a stable structure through artificial ageing.

Heat treatment can be performed at a temperature of between 300 °C and 550 °C for a half an hour to several hours.

While pouring the cylinder crankcase, the melted mass temperature preferably exceeds the melting point of the bonding layer of the cylinder bushing, so as to melt the bonding layer to its surface while casting to improve the material bond.

The formation of a boundary surface between the casting material and cylinder bushing is influenced greatly by the pouring procedure used. While the gravitational procedure can be used for pouring, pressure-supported pouring procedures are preferred over no-pressure pouring procedures according to the invention.

In pressure-assisted pouring procedures, applying an outside force while filling the casting mold and during

the setting process results further increases the level of material tight bond. This holds true in particular when pouring with a pressure-assisted procedure at a gating rate of more than 1 m/s. In pressure-assisted pouring procedures, in particular high- and medium-pressure pouring procedures, the melted mass is pressed into even the finest of hollows. The complete closure with a greatly enlarged surface yields ideal conditions for a material tight connection as well. The specific setting of the mold fill rate and temperature ranges makes it possible to further optimize the material bond. The following example is intended to further explain the invention.

<u>Example</u>

A mandrel (hollow mandrel) made of tool steel with a amount of taper of 0.5° is allowed to rotate at a speed of 180 RPM. A zinc wire is used to flame spray an externally cylindrical carrier layer with a thickness of approx. 70 µm onto the mandrel at a spraying distance of approx. 100 µm to 150 µm.

At the same rotational velocity and spraying distance, a 2 mm thick running surface layer is applied to the carrier layer via plasma spraying with an Al-Si alloy powder having an Si content of 25 %w/w and a grain size (sieve fraction) of 10 µm to 125 µm. At the same rotational velocity of the mandrel and identical spraying distance, a roughly 300 µm thick bonding layer is then applied via flame spraying with an Al-Si alloy powder having an Si content of 15 %w/w and a grain size (sieve fraction) of 90 µm to 250 µm.

The mandrel is quenched with cold water, and thereby detached from the still hot cylinder bushing blank via shrinking.

The blank is then placed on the barrel in a casting mold, and poured in via pressure casting with an Al-Si alloy having an Si content of 9 %w/w. After removal from the mold, the carrier layer is removed via machining, and the running layer is sized to the cylindrical operating dimensions.

An ultrasonic analysis reveals that over 90 % of the bonding layer relative to the cylindrical jacket surface of the bonding layer is bound with the casting material in a material tight manner.